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Copper in Wines and Vineyards: Taste and Comparative Toxicity to Pesticides

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Abstract

Vines are among the crop plants that are most heavily treated with pesticides. Two of the authors have previously characterized the taste of pesticides in water and wines. In light of a current debate, in this paper we have summarized data on the taste and potential toxicity of Copper (Cu) in wines, as well as on the necessity of its use in vineyards, and in organisms in general. Copper has been considered as an organic pesticide. We underline here that it is protective of life and only toxic by saturation of the capacity of physiological processes. It is found at an average dose of 0.15 mg/l in organic wines, and at up to 1.5 mg/l or more in non-organic ones, probably because of its presence in the composition of synthetic pesticides. It is detectable in water by taste from 0.075 mg/l. Its taste is characterized in the present work. Tasters were able to detect the taste of copper in a wine spiked in a blinded manner to a level of 0.15 mg/l. When added at 1 or 1.5 mg/l it was found to clearly modify the taste of wine. At a level of 0.15 mg/l, it would be necessary for a human of 80 kg to drink 80 l of organic wine per day to reach the threshold of acute toxicity of copper. On the other hand, a medical prescription of copper can stimulate the immune system of an adult at a level of 1 mg/day. For comparison, we found that a favourably judged (awarded 100/100 in the Parker Guide) non-organic bottle of wine contained 146 ppb of boscalid, a widely used synthetic pesticide. If we consider the formulants and residues present in numerous pesticides, such as petroleum and arsenic or other heavy metals, the threshold of chronic toxicity will be reached from the consumption of 22 ml of this wine. Similar results are obtained for fenhexamid and glyphosate in Roundup, which have a considerably higher toxicity than an excess of copper. Copper cannot therefore be considered as being comparable with the synthetic pesticides derived from petroleum that are present in non-organic wines, in contrast with the recently published views of regulatory bodies. Moreover, the environmental impact of copper in organic vineyards under normal treatment appears to be positive, in that it improves biodiversity, in contrast with the impact of synthetic pesticides.

Introduction

Since the 1950s, vines have been among the crop plants that are most heavily treated with pesticides. For instance, in France, which is known as a wine producer, 20% of the pesticides, in tons, sprayed nationwide are used on vineyards, which, however, represent only 3% of all cultivated land [1]. Wine has been a very symbolic drink since the beginning of human cultures, in particular in religions. Important economic exchanges have been linked to its market. Quite often, chemical pesticides are sprayed prior any disease in fields as an insurance or a proposed practice of protection, even if this could alter the defence mechanisms of the plant on the long term. No evidence exists that pest attacks are greater on vines than in other plants. Organic vineyards are in development. Copper (Cu) salts and sulphites are authorized in organic wine making. They are often called bio-pesticides because they are the most frequently used treatments in organic production. In this mini-review, we will investigate the role of Cu and how it compares with other pesticides, because it is a highly debated subject.

It has long been known that Cu is essential for plants but that it is also toxic in excess. Cu homeostasis is necessary in many organisms for mitochondrial respiration [2], lignin and chlorophyll synthesis, plant metabolism and growth, response to stress, and also flavour and colour. Similarly, in animals, due to its redox potential, this trace element is a cofactor in many enzymes responsible for important processes in cells, such as detoxication. It is a highly reactive element in its free state: in excess it can trigger the production of free radicals, damaging proteins, DNA, and any organic macromolecule, as well as inhibiting essential respiration enzymes. It is also essential for spermatogenesis [3].

Bloodnick (2018) [4] underlines in horticulture that the normal range in a growing medium is 50-500 ppb and that it is bio accumulated in most tissues to a level of 3-10 ppm. At these levels, it is protective of life and a necessary trace element. Like many compounds, it has balanced stimulating and inhibiting effects, depending on time, dose, environment, and sensitivity of the target. For these reasons, the use and toxicity of Cu is debated. It is sold as a pesticide, although it is often first used as a defence-stimulating agent for plants after a deficiency is noticed. Many plants can in this way produce more natural repellents and aromas to repel parasites. Of course, a natural equilibrium of many other trace elements and vitamins is also necessary. When used at environmentally toxic levels or in combination with toxic compounds, it will saturate the detoxification system, including that of parasites; therefore, it appears to work as a pesticide in the short term at high levels. The detoxification and sensitivity may begin by indications given by the taste of food and drinks in healthy humans [5]. For this mini-review, we have studied the levels, taste, and toxicity of Cu in wines. We have also reviewed and compared the use of Cu in chemically-treated and organic vineyards.

Levels of Cu in Organic and Non-Organic Wines

Cu exists in different molecular forms in grapes and commercially, including as free radicals (Cu^{2+}) and as interconvertible hydroxide and sulfated ions [6]. A detailed study from Provenzano, et al. (2010) [7] has shown that in Italy the level of Cu in organic wines ranged from 0.1-0.4 mg/l. In France [8] the average level of Cu in organic wines was established at 0.15 mg/l. It is admitted that Cu is the major chemical component authorized for treatments of organic cultures. Of course, some media publish claims that all organic wines contain the pesticide Cu [9]. However, Cu is essential for life and thus is not a synthetic pesticide, and all wines and living organisms naturally contain some Cu, for the reasons detailed above. It should be underlined that higher mean levels of Cu are found in non-organic wines throughout the world. It is understood in many countries that the limit should be 1 mg/l. The presence of Cu is mostly linked to the number and timing of fungicide applications. In addition to the declared active substances, most formulations of synthetic pesticides contain heavy metals and other trace elements [10], including Cu. Petroleum residues have even been found in formulants [11], the identity of which is generally undisclosed and kept as confidential business information, as well as heavy metals such as arsenic [12].

In treated wines in Croatia, up to 7.6 mg/l of Cu was detected [13] and in Australia up to 15 mg/l Cu were found in non-organic must and raisin juice before fermentation. It has been long known (Tromp and de Klerk, 1988) [14] that from 10 mg/l it inhibits fermentation, as do agrochemicals residues, but often this is compensated for in treated wines by adding significant amounts of modified yeasts. This is by the way a common practice in wines when fungicides are applied in the vineyard and detected as major pesticides in non-organic wines [5], since most natural yeasts are killed by fungicides. In brief, more Cu and cupric residues are found in non-organic wines, either white or red, than in organic ones, due to less chemical applications in the latter case, and maybe more time (40-50 days) between the last application and the harvest. This is noticeable in Italy [10], the USA, and Australia [15], even if the Cu levels in some wines are around the level of organic ones. Using the atomic absorption analytical procedure, in France, Fournier, et al. [6] found in an itemized research from 0.6 to 1.5 mg/l of Cu in non-organic wines, as well as zinc and lead. This upper level, even in today's more regulated environment, is still around 10 times more than the average level in organic bottles.

The Taste of Cu in Water and Wine

Many variables can change the tastes of wines - including the variety, maturation, soil, leaf removal during growth or time of harvest, chemical treatments, seeding by aromatic yeasts, or aging and processing by methods chosen by the winemaker. Of course, the final composition results from all parameters. Among those, we have demonstrated that pesticides play a role [5]. Numerous pesticides have been classified as endocrine or nervous system disruptors [16,17]. The receptors for these aromatic and/or steroid-like compounds may resemble each other, even in the olfactory system, at least in the capacity of these molecules to bind an active site, whether irreversibly or not. Therefore, we examined whether the taste of Cu, which is considered in some instances a biopesticide, was comparable to the taste of the synthetic pesticides found in wines [5]. We also examined whether it could be detected when present in water, in isolation, at the same levels as in the wines.

A total of 30 volunteers accustomed to drinking wines were recruited for the experiment. They included chefs and retailers. This primary detection of Cu in water was not conducted as a usual sensory taste: it was a preliminary trial to know the feasibility of the detection of Cu in isolation by humans, at the minimal level found in wines; and to find out if the taste, including the smell, was describable at all. It was astounding to observe the repeatability of the results. Testing was processed silently and independently, with the results being recorded in writing, as already described for pesticides testing [5]. We asked the tasters to describe the tastes detected in water in a few key words. In a first step, dissolved and drinkable Cu (Laboratoire des Granions, Monaco) was presented at 0.15 mg/l in water devoid of this element, in a blinded manner. All glasses were similar and were filled with around 30 ml of water. 3 ml was the mean enough consumption for this first detection. This was not organized as a classical sensory test because the tastes of these types of products were previously unknown by the participants in food or drink; this is called a primary test.

The glass containing Cu was detected in all instances from the first drops in the mouth. Thus, the number of 30 tasters was considered to be enough. Only 12/30 of the tasters recognized it by the nose; and 30/30 by mouth, differentiating it from pure mineral water. Sensations were collected: mineral or metallic, the mouth dries, the taste is light, but calcareous, like stone. The tongue lightly grates, or sticks, or feels thick; that can be due to a papilla blockade. A milky taste is sometimes described (Table 1). Among those who described well the nose detection and described the taste at 0.15 mg/l, one of us (JCH) was able to recognize the glass containing 0.075 mg/l, i.e. 75 ppb. Cu was then spiked (from 0.15 mg/l) in a wine, and the spiked glass was easily recognized. It breaks the complexity of nose and mouth sensations, according to specialists, especially for red wine. The description was easier for white wine: a brisk nose and a slightly acidic taste. Around 1 mg/l, it was always identified in comparison with the same natural wine that was not spiked and negatively disrupted the taste for tasters.

Summary of Cu smell or taste	In water at levels found in wines at 0.15 mg/l	In wines when spiked at same level
By nose	12/30 detected	Yes, all
By taste	30/30 from 0.15 mg/l (1 professional at 0.075 mg/l)	Yes, all
Description by order	Mineral or metallic	Brisk nose, slightly more acidic taste in white wine
	Calcareous, stone	Breaks the complexity in red wine
	Dries, grates, sticks, thick (on tongue, light)	
	Milky	

Table 1: Summary of Cu smell or taste. Volunteers were asked to describe the nose or mouth detection in primary and preliminary testing at the minimal level of Cu that was found in organic wines. The result was very clear. Further sensory tests could be organized.

When eco-labelled and regular wines were tasted, without respecting similar varieties, soils, and years, in another large study using 74,148 bottles from 3,842 Californian vineyards, the organic wines were also significantly preferred [18]. This was confirmed in our results with French wines in a blinded manner, but using this time similar varieties, soils, and years, for two neighbour vineyards, one being sprayed with synthetic pesticides, the other not [5]. The tastes of organic wines in our experiment were judged to be less artificial and to last longer, and the overexpression of artificial aromatic yeasts is never the case for natural wines. Natural yeasts could however be more difficult to control, with a greater year-specific variation. In this work, we provide evidence that Cu concentration may influence the taste of wine, and thus this could also explain, at least in part, why natural wines with less Cu may be preferred to wines with synthetic pesticides. Most Cu-containing agricultural inputs are fungicides [5], and several fungicides have Cu as their active ingredient or in formulations, and some will be absorbed through the leaves [4]. Copper pollution has been found to affect the phenolic compound content, colour, and antioxidant activity of wine, which must change the taste [19].

Necessity and Toxicity of Cu

The necessity of Cu as a constitutive element in, and cofactor for, crucial enzymes, as well as an essential trace element for plants, animals, humans, and fungal and microbial cells, is widely demonstrated [20]. Its balance regulates homeostasis. Therefore, it cannot be considered as a biopesticide, even if it is sold as such. Its toxicity by overdose is due, among other possible mechanisms, to the inhibition of crucial enzymes. Any enzymatic or hormonal reaction exhibits a bell curve in the presence of increasing doses of its ligand or substrate. Moreover, it can saturate the detoxication system of any living organism. Excess Cu in plant growing medium can restrict root growth by burning the root tips and thereby causing excess lateral root growth. High levels of Cu can compete with plant uptake of iron and sometimes molybdenum or zinc. The new growth can become initially greener than normal and then exhibit symptoms of iron deficiency or possibly other micronutrient deficiencies. If not corrected, Cu toxicity can reduce branching and eventually plant decline follows [4].

In humans, some medical prescriptions are made for 1 mg Cu/day, in particular to stimulate the defence and immune system. Hepatic and kidney failure may occur when an excess of Cu is consumed, since they are the detoxification organs. If we consider the admissible daily intake for humans of 0.15 mg/kg/day, an 80 kg person can ingest 12 mg of soluble Cu (interconvertible forms) per day. For an average of 0.15 mg/l in organic wine, 80 l must be consumed per day to reach the acute toxicity of Cu, which is unrealistic, but for a non-organic wine only 8 l on average would have to be consumed (if its content is 10 times more in general). For chronic toxicity, we will have to consider the fact that Cu is included in toxic formulations of fungicides [10]. This theoretical difference is interesting, even if for these quantities, alcohol is far more toxic (Table 2).

Compound	In organic wines µg/l	In non-organic wines µg/l	Long term toxicity in formulations µg/kg/day	Quantity (for a 80 kg body) to reach the compound toxicity in ml/day
Copper (Cu average)	150	1500	(in organic)150 (in non-organic) 0.15*	(in organic) 80,000** (in non-organic) 8,000**
boscalid	0	146	0.04*	22
fenhexamid	0	500	0.37*	59
glyphosate	0	11	0.1*	727**

Table 2: Quantities of copper in wines and comparative toxicities to some petroleum-derived pesticides. The quantities of Cu in wines are from the text above; levels for the other synthetic pesticides boscalid, fenhexamid and glyphosate are the actual maximum levels found in our previous study in some current wines. *The long-term toxicity of formulations takes into account the presence of petroleum-derived residues and heavy metals and the combined measured toxicity in human hepatic cells (minimum 1000 x ADI, see text). Cu is not present in petroleum-derived formulations for organic use, but it is present in the formulations of petroleum-based synthetic pesticides. The quantities per day needed to reach toxicity for a human body of 80 kg are thus compound-specific. Obviously, the toxicity threshold for alcohol will be reached before that for Cu.** This is not the case for boscalid and fenhexamid present in non-organic wines, nor is it the case overall if we consider the combined effects of all pesticides present besides these examples, which may number 5-6 [5]. Fungicides are more toxic in general.

Comparison of Toxicity with Common Synthetic Pesticides

WWe will compare the acute and chronic toxicity of copper to that of three relevant substances: the major characteristic fungicides detected in wines in our previous study, boscalid and fenhexamid [5], and to the glyphosate-based herbicide Roundup [21], the most frequently used herbicide in vineyards and also the most used (and most controversial) herbicide in the world, since glyphosate was also detected in this study in wines. The most expensive wine (400 euros, 75 cl) was non-organic, from 2009 and very well known: it was marked 17/20 by wine critics Bettane and Dessauve, 18/20 by Gault and Millau, 97/100 by Wine Spectator, and was given the supreme ranking in the Parker guide: 100/100. It contained 146 ppb of boscalid, recognizable by taste. These classifications do not consider pesticide content. This also represents 146 µg/l, two times less than the average found in wines treated by synthetic petroleum-derived pesticides and 1460 times the level authorized in drinking water in France (0.1 µg/l). The ADI for boscalid is 0.04 mg/kg bw/day, according to the European Union Pesticides Database. It is already 3.75 times more acutely toxic than Cu, but this is still an admissible level for regulatory authorities. For long-term toxicity, we must consider the petroleum and heavy metal residues in the formulation. In a boscalid-based one there are more than 300 ppb arsenic, around 300 cobalt, 1000 chromium, 600 nickel [12]. This can be sprayed on vineyards and can very easily enter the human cell membranes; it will increase the toxicity and endocrine disruption by at least 1000, especially in hepatic cells [22,12,16]. This more realistic type of toxicity will be then reached for 0.04 µg/kg bw/day. For a human of 80 kg this will correspond to 3.2 µg consumed per day. It means that 3.2 µg will be reached by consuming 22 ml of this wine (Table 2). Boscalid has a chlorine or burning taste which is detectable by trained professionals at this level [5].

The calculation is comparable for fenhexamid. In petroleum-derived formulations, in addition to petroleum derivatives shown to be toxic to hepatic cells, as we previously demonstrated (Mesnage, et al. 2014) [22] the heavy metals are in ppb around 500 for arsenic, 800 for chromium and the same for nickel [12]. Consequently, the toxicity level of this mixture is at least 1000 times the ADI, i.e. 0.37 µg/kg bw/day (Table 2). This equates to just 59 ml of wine, corresponding to approximately half a glass. Fenhexamid has a surprisingly sweet chemical and artificial strawberry taste, in addition to the drying and papilla blockade effects common to all synthetic pesticides [5]. For these two fungicides sprayed in pesticide formulations and found in wines, the chronic toxicity appears to be greater than that of alcohol. The chronic toxicity during applications in the vineyards has long been demonstrated, for instance with regard to bladder cancer [23]. Cu cannot be considered to be comparable in any way to synthetic pesticides, for all these reasons.

The last example, of glyphosate-based herbicide, has been invoked because it is the most used pesticide in the world and the main herbicide used in vineyards. Roundup does contain glyphosate (around 40%) but also petroleum derivatives (Mesnage, et al. 2013) [11] and arsenic up to 500 ppb, in common with other heavy metals depending on the formulation [12]. Its chronic toxicity has been documented in vivo from 0.1 ppb (µg/l) (Seralini, et al. 2014) [24] and even up to 100,000 times more than glyphosate, depending on the type of human cells and the time of exposure [25,26]. Its effects below regulatory limits, though controversial, have been reviewed [27]. Liver and kidney lethal deficiencies due to ultra-low doses (0.1 ppb) of Roundup have been confirmed more recently by multiomics techniques [28,29]. In general, 10-11 ppb (110 times more) of glyphosate were discovered in several wines [5]; the calculation in Table 2 has been performed from this basis. Still, glyphosate is 12-33 less toxic than fungicides. Cu is not toxic on the same scale at all. It is also essential.

Environmental Impacts in Comparison to Synthetic Pesticides

In a secondary way, this experiment allowed us to test the comparative environmental impact between Cu and the synthetic pesticides used in neighbouring vineyards. In a previous study (Seralini and Douzelet, 2017) [5] we demonstrated that in 16 neighbouring vineyards, with the same variety and the same year, organic wines revealed traces of contamination with chemical pesticides only once, below the quantitative limit of assessment. Yet contamination with chemical pesticides was found in all instances except two in so-called conventional wines, with a mean of 293 ppb and up to 1144, in the neighbour vineyards treated with pesticides. All organic wines used Cu in limited amounts (in general less than 3 kg/ha/year in France). The contrast in the ecosystem is remarkable (Figure 1).

Figure 1: Examples of neighbour vineyards in winter. On the left, the field has been treated in Alsace by synthetic pesticides, on the right, vineyard prepared for natural wine: no petroleum-derived chemicals, little Cu. In the latter in February, radish, oat, clover and other plants have been seeded simultaneously in the vineyard to improve biodiversity and natural yeasts. On the left, the soil is brittle and light with a putrid smell. On the right it is sticky and rich, with humus odours, and living.

The plantations may include co-cultures in organic vineyards. This and other spontaneous plants like dandelion may detoxify the soil and environment, explaining the absence of synthetic contaminants in organic wines. Even after a sporadic contamination by the neighbour's spraying, the vineyard using no synthetic pesticides is around a hundred times less contaminated, if we consider the resulting wines. It is known that some plants here observed can detoxify living organisms (Gasnier, et al. 2010, 2011) [30,31] and soil [32]. This has rarely been explained before. Many people suppose that organic vegetables must be contaminated by the pesticide spraying of neighbour farmers, and that this will result in the presence of unwanted pesticide residues anyway. It is not the case. Moreover, the resulting biodiversity in organic vineyards is important (Figure 2) overall, in comparison to vineyards treated with synthetic pesticides (Figure 3). This largely agrees with the conclusions of a review of the impacts of pesticides used in agriculture [33], which are becoming more generally known.

Figure 2: Biodiversity in organic vineyards. In autumn (left) or spring (right, plants and flowers are numerous). This dense biodiversity does not exist in treated vineyards. Interestingly, detoxifying plants such as dandelion are visible (on the left), that may explain why organic wines are devoid of pesticides even if the neighbour sprays them. A hundred times less pesticides reach organic vineyards by rain or neighbours, and the living soil and plants appear to be capable of detoxification, resulting in the non-detection of synthetic pesticides in organic wines in our study.

Figure 3: Treatment by synthetic pesticides in a vineyard. Chemical treatment in comparison to Figure 2 where the vineyard is not sprayed with synthetic pesticides. No biodiversity is noticeable here. Cu is present at high doses with heavy metals such as arsenic in formulated pesticides, together with petroleum residues, especially fungicides and glyphosate-based herbicides. The ecosystem is killed together with its detoxification capacities; no other plants except the vines in the figure.

Conclusion

Cu cannot be considered as comparable to petroleum-derived synthetic pesticides present in non-organic wines from any point of view. We were able to differentiate Cu toxicity levels in organic and non-organic treatments due to the combined effects of petroleum derivatives in the latter case. Moreover, the environmental impact of copper in organic vineyards under normal treatment appears to improve biodiversity, in contrast to the use of synthetic pesticides.

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